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Performance and Operational Upgrades of X-ray Streak Camera Photocathode Assemblies at NIF

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ABSTRACT

X-ray streak cameras are used at the National Ignition Facility for time-resolved measurements of inertial confinement fusion metrics such as capsule implosion velocity, self-emission burn width, and x-ray bang time (time of brightest x-ray emission). Recently a design effort was undertaken to improve the performance and operation of the streak camera photocathode and related assemblies. The performance improvements include a new optical design for the input of UV timing fiducial pulses that increases collection efficiency of electrons off the photocathode, repeatability and precision of the photocathode pack assembly, and increase the input field of view for upcoming experiments. The operational improvements will provide the ability to replace photocathode packs between experiments in the field without removing the diagnostic from the Diagnostic Instrument Manipulator (DIM). The new design and preliminary results are presented.

Keywords: National Ignition Facility, NIF, X-Ray streak camera, 4ω fiducial, photocathode, inertial confinement fusion, x-ray diagnostics, SPIDER, DISC

1. INTRODUCTION

The National Ignition Facility (NIF) uses x-ray streak cameras in different experimental campaigns to record time-resolved x-ray spectra and radiography data. The NIF x-ray streak cameras include SPIDER (Streaked Polar Instrumentation for Diagnosing Energetic Radiation) [1] and DISC (DIM Imaging Streak Camera) [2,3]. Both have identical Kentech [4] electron optic streak tubes and similar electronics. For the upgrades described herein, the most important operational feature is that the new photocathode pack is field-swappable, meaning the pack can easily be exchanged in the NIF Target Bay by hand without unloading the streak camera from the DIM (a huge improvement for efficiency of operation). This required designing the EMI shield and photocathode pack as self-aligning, tool-less, quick release assemblies which could also maintain the tight tolerances required for the positioning and alignment of the parts. In fact it will be shown below that the new design provides better control of the position and orientation of parts in the photocathode assembly. This assures greater repeatability and consistency in performance from one photocathode pack to another, and reduces the need for time-consuming characterization of each photocathode pack individually.

Another feature implemented on the streak cameras is a fiducial timing comb on the streaked image from a 263nm UV pulse train (fourth harmonic of 1053nm, or 4ω). The 4ω fiducial timing pulses (4ω FIDU) are used to measure sweep linearity and cross-timing relative to the NIF laser, as well as providing the ability to do "dry run" operational checks of the instrument before and after experiments. The original design to inject the 4ω FIDU pulses onto the photocathode used a low divergence (0.12 NA) fiber tip placed 1mm from the back of the photocathode to minimize the optical spot size. Small 4ω FIDU spot size is desirable to optimize temporal resolution and to increase the

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energy density of the UV light (producing a brighter signal in a smaller area). This original design required cutting a hole near the edge of the accelerator grid for the fiber tip to pass through, and the edges of this hole created unwanted fringing electric fields between the photocathode and the grid. These fringing fields deflect a large fraction of the electrons excited from the photocathode by the 4ω FIDU pulses, thereby reducing the collection efficiency onto the detector and making it difficult to resolve the UV pulse train in an experimental image due to poor signal-to-noise ratio. The hole in the accelerator grid also affected the ability to collect x-ray data by creating an unusable area or "dead zone" on one side of the photocathode, even if the 4ω FIDU was not used. The upgrades described herein address these issues by eliminating the hole in the grid and instead using optics to project the 4ω light from the input fiber through the grid into a small focused spot on the photocathode.

An important driver for the current upgrades was the need to support a new diagnostic, the NIF X-ray Spectrometer (NXS) [5], which is mounted on DISC to recorded time-resolved x-ray energy spectra in the range from 2 to 18 keV. The NXS uses crystals to reflect x-rays onto the streak camera photocathode from oblique angles, and thus required a wider aperture in the EMI shield and wider field of view for the input to the photocathode pack.

2. DESCRIPTION OF STREAK CAMERA AND 4ω FIDUCIAL SYSTEM

Figure 1 shows the key functional parts of an x-ray streak camera. X-rays incident on the photocathode (biased to ≈ -15 kV) produce photoelectrons which are then accelerated through a grid into the streak tube electron optics. After passing through the anode aperture, the electron beam passes through a set of deflection plates (in the sweep region) to which a fast voltage ramp is applied, causing the beam to sweep across the imager/detector as a function of time. This converts a fast temporal signal into a spatially-resolved image on the detector.

The 4ω FIDU system [6,7] currently delivers three 263nm pulses with a separation of 600ps. The 1053nm seed pulse is generated in the NIF Master Oscillator Room (MOR), which is then split into three pulses, amplified, and converted to 4ω before being delivered to the rear of the photocathode in the streak camera. There the pulses generate bursts of photoelectrons which become the timing fiducial spots in the x-ray streak camera image. See Figure 2 for a detailed block diagram of the 4ω FIDU system.

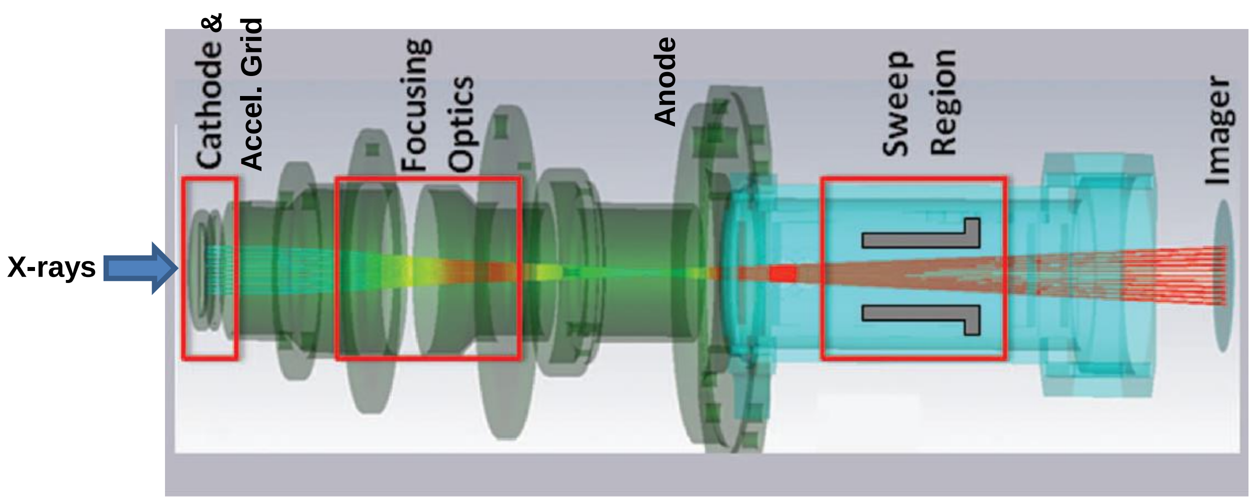


Figure 1: Schematic of x-ray streak camera key functional components (adapted from Ref. 3). The fiber that carries the UV light to the photocathode for the 4ω FIDU signal is not shown.

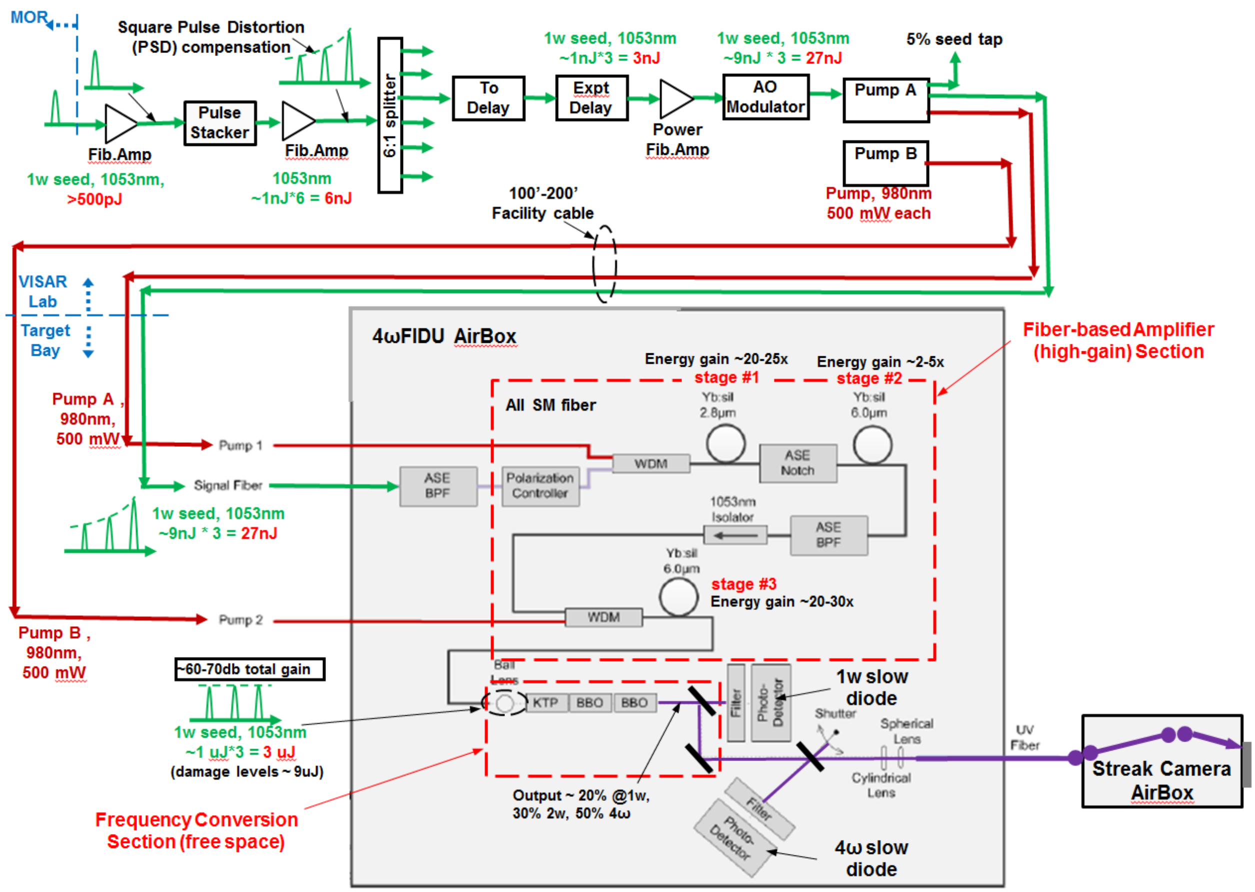


Figure 2: Block diagram of 4ω FIDU System. Definitions: AO (Acousto-optic) Modulator, ASE BPF (Amplified Spontaneous Emission Bandpass Filter), WDM (Wavelength-division Multiplexer)

3. DESCRIPTION OF UPGRADES

During the initial stages of implementing the 4ω FIDU system on the x-ray streak cameras used in NIF, much more UV energy was required than expected in order to produce an adequate signal level of at least 100 counts above background for the fiducial spots. There were also issues with lack of repeatability between photocathode pack assemblies and accelerator grids. See Figure 3 and Figure 4 for images of the original design.

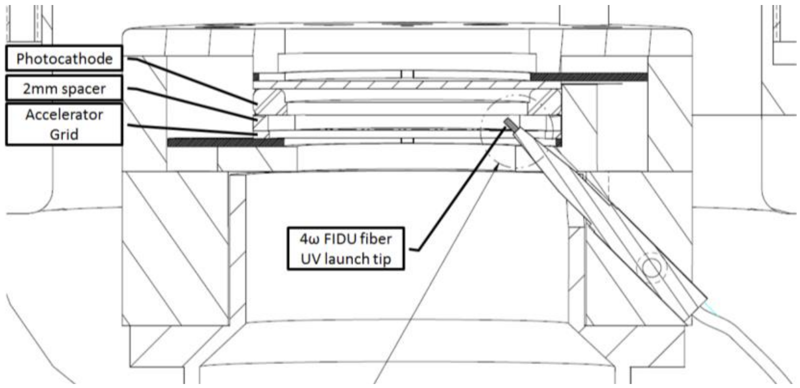


Figure 3: Cross section of original photocathode pack and 4ω FIDU launch fiber. The fiber tip is nominally 1mm from the surface of the photocathode, extending through a hole in the accelerator grid.

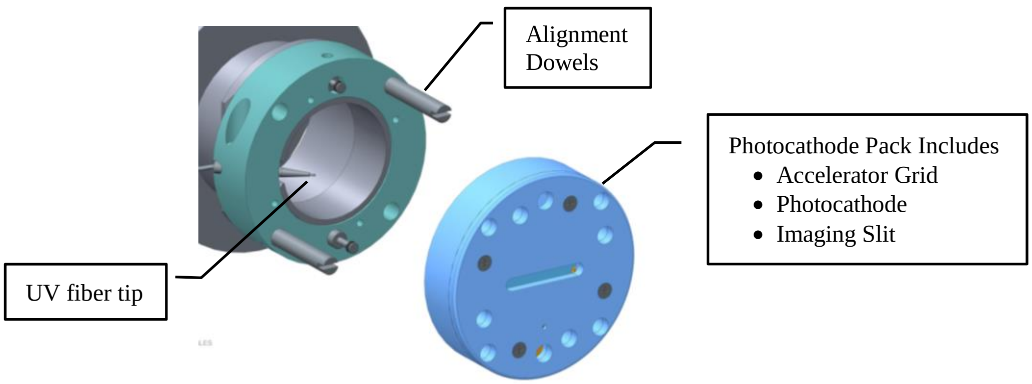


Figure 4: Front ISO view of original photocathode pack design.

To better understand the effect of the hole in the accelerator grid, simulations were performed using a 3D multiphysics model of the streak camera to track electric fields and electron trajectories [8]. The simulation showed that the fringing electric fields around the edges of the hole in the accelerator grid cause a lensing effect that deflects photoelectrons leaving the photocathode in the region around the hole. This effect reduces the collection efficiency of the 4ω FIDU signal and deforms the shape of the FIDU spots in the streak camera image. Figure 5 shows the results of the simulations. As the electrons travel through the electron optics (between the photocathode and the anode), many of the deflected electrons hit the anode plate instead of passing through the aperture in the center. These missing electrons account for the "Dead Zone" of the instrument — the region on the photocathode from which no image is formed because the electrons are deflected and do not make it through to the detection plane. The bottom image in Figure 5 shows actual data from an unswept image which is comparable to the simulations, showing the dead zone caused by the hole in the accelerator grid.

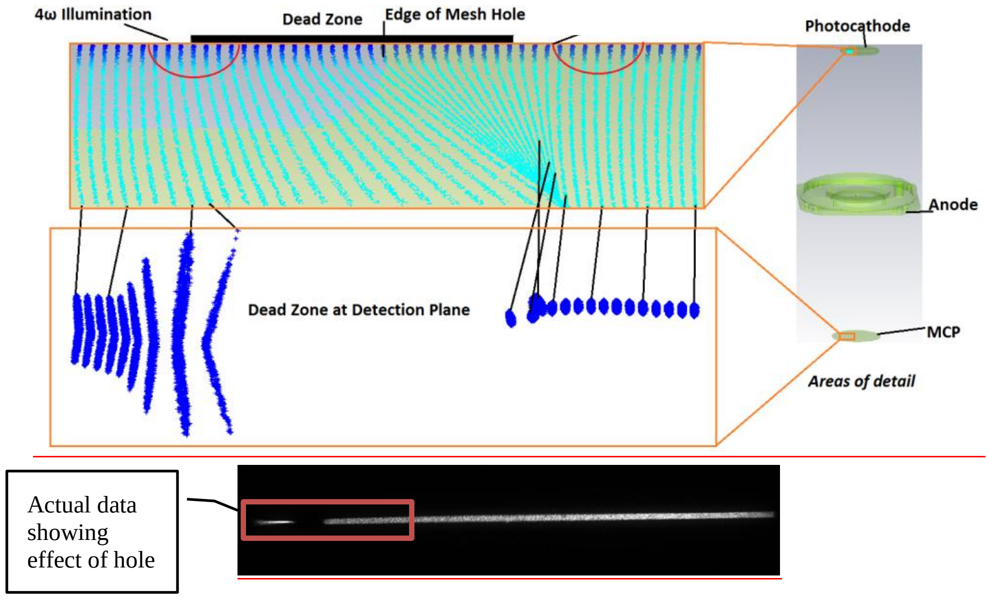


Figure 5: Simulation of electric fields (not shown) and resultant electron trajectories (light blue paths in top image) in the vicinity of the hole in the accelerator grid (also called "mesh"). The middle image shows the predicted shape at the detector plane of the spots from each electron beam. The bottom image is actual data from an unswept streak camera image showing the dead zone due to the hole in the mesh, comparable to the simulations.

To eliminate the need for a hole in the accelerator grid a new design was developed utilizing UV optics to focus the 4ω FIDU pulses onto the photocathode from 10mm away through the accelerator grid's standard open area regions. This new design allows for use of the full area of the photocathode for x-ray imaging when 4ω FIDU is not used, and it increases the detection efficiency of the 4ω FIDU signal electrons leaving the photocathode. See Figure 6 for images of the new 4ω FIDU input optics.

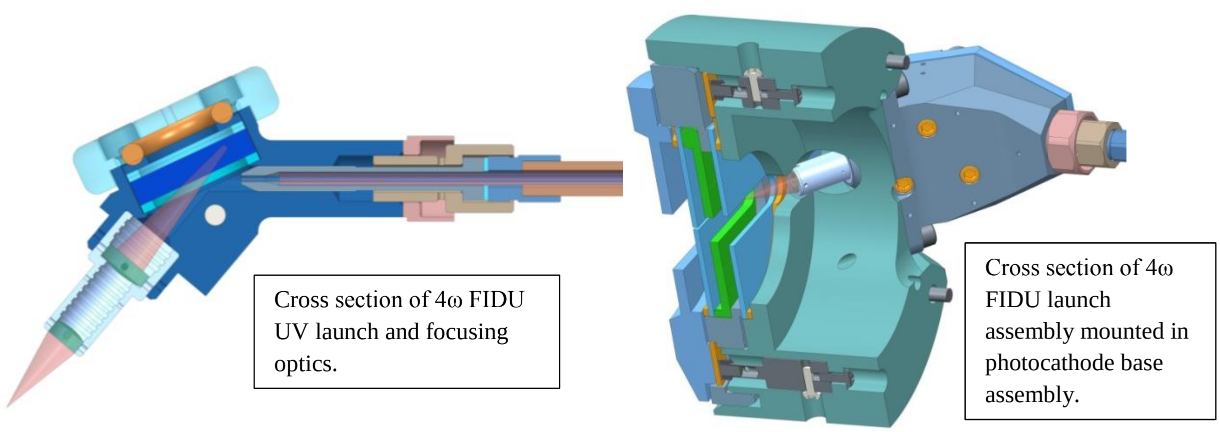


Figure 6: Cross-sectional views of new 4ω FIDU UV optics

In the new design, the accelerator grid was removed from the photocathode pack and incorporated into the base that is affixed to the electron optics tube assembly. With this change in design, the x-ray streak camera's imaging performance is less likely to be affected by replacing photocathode packs. Another benefit of the new design is the ability to easily and safely replace photocathode packs in the field. By using large alignment pins with keyed orientation and captured screws, these new photocathode packs can be replaced without unloading the diagnostic from the DIM (with only the limited access and visibility afforded by the side ports on the DIM), greatly reducing setup time between NIF experiments when a photocathode change is required. A dry run system using 4ω FIDU also gives NIF Operations the ability to verify the photocathode pack replacement was successful prior to the next shot. See Figure 7 for images of the new photocathode pack and base assembly.

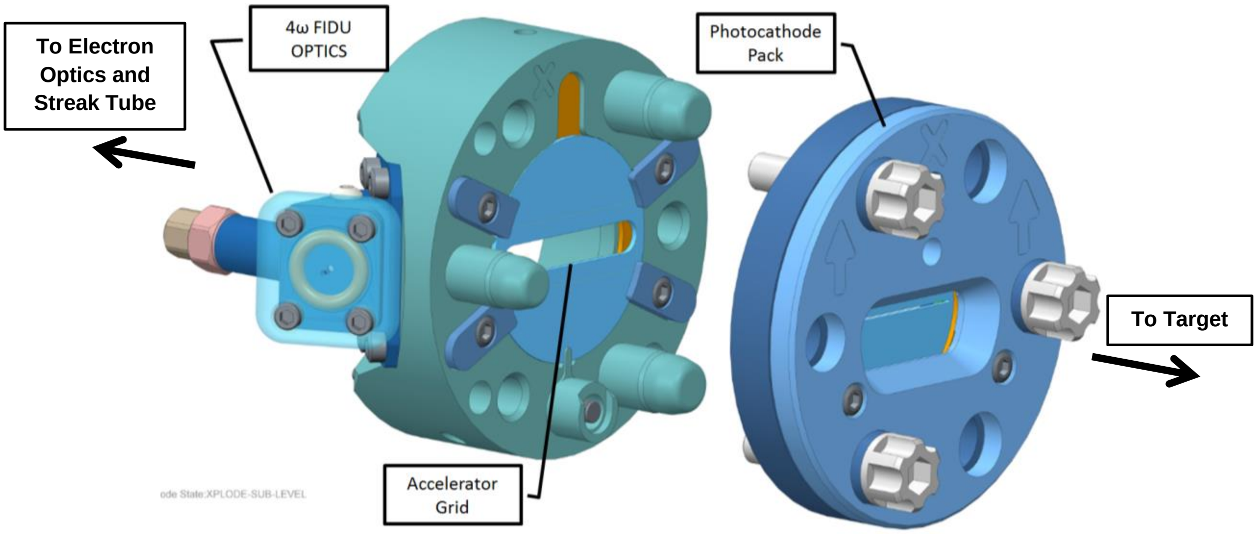
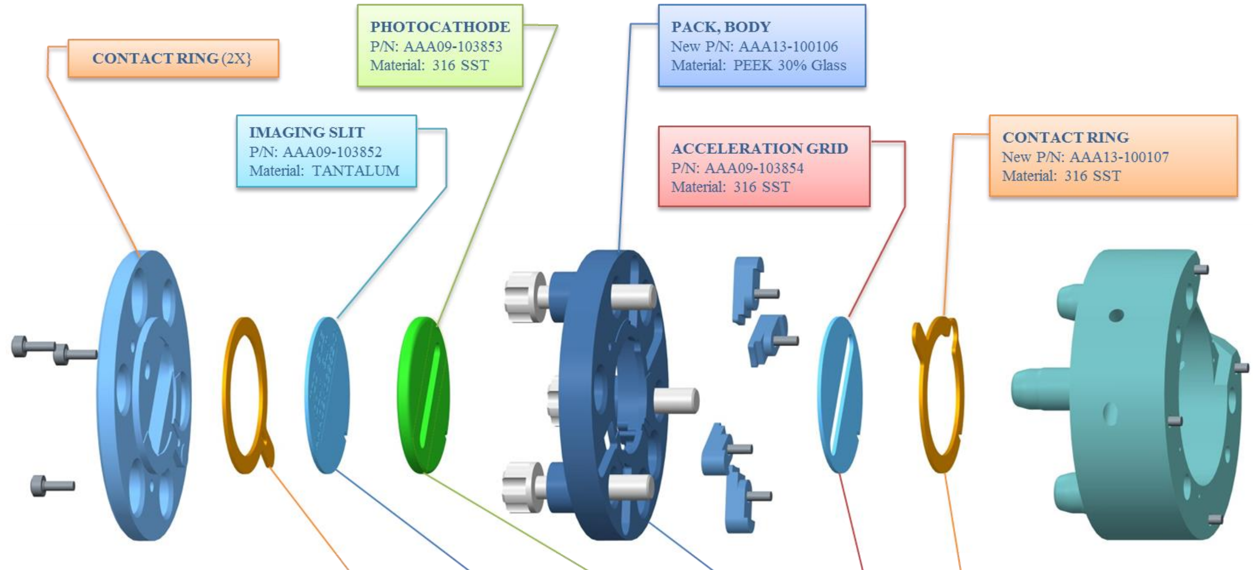


Figure 7: New photocathode pack and base assembly. The 4ω FIDU UV optics are mounted to the base which is attached to the electron optics tube of the streak camera.

To ensure the new design could meet the requirements for controlling position and orientation of the parts in the photocathode assembly, a tolerance stack-up check of the system was performed. This check verified that the 2mm gap between the photocathode and accelerator grid will be maintained within 200um when exchanging photocathode packs. Rotational alignment tolerances ensure that the angle of the imaging slit will be maintained within ± 0.6 degrees (± 10 mrad) for all photocathode packs. Figure 8 summarizes some of the key tolerances for the photocathode parts and highlights how those tolerances have been improved over the original design.

Along with the new photocathode assembly and UV optics, a new EMI shield was developed to allow easy access to the pack. This quick-release EMI shield design requires no tools to remove or install, providing easy access to the photocathode pack for replacement inside the DIM. Figure 9 is a model image of the new design and a photograph of the actual EMI shield installed on a DISC. Along with reducing maintenance and setup time, the new EMI shield provides a larger aperture for x-ray imaging to support new diagnostics such as the NIF X-ray Spectrometer (NXS) [5].



Thickness was:	+ 0 / - 0.13	+ 0 / - 0.15	+/- 0.3	+ 0.12 / - 0.05	1 STK	+ 0 / - 0.13
	[+.000 / -.005]	[+.000 / -.005]	[+/-.011]	[+.004 / -.001]	[.039] STK	[+.000 / -.005]
Thickness is:	+ 0 / - 0.05	+ 0 / - 0.10	+/- 0.05	+ 0 / - 0.05	+ 0 / - 0.10	+ 0 / - 0.05
	[+.000 / -.002]	[+.000 / -.004]	[+/-.002]	[+.000 / -.002]	[+.000 / -.004]	[+.000 / -.002]
Alignment was:	0.25 [.009]	0.25 [.009]	0.25 [.009]	0.30 [.011]	0.25 [.009]	0.25 [.009]
Alignment is:	0.05 [.002]	0.10 [.004]	0.10 [.004]	0.05 [.002]	0.10 [.004]	0.05 [.002]

Figure 8: Break down of photocathode pack tolerances and comparison to original design. "Thickness was" means thickness tolerance in original design, while "Thickness is" refers to new design. Alignment numbers are the tolerances for features on the parts that control rotational alignment, such as tabs and slots. The precision of the assembly has been improved significantly.

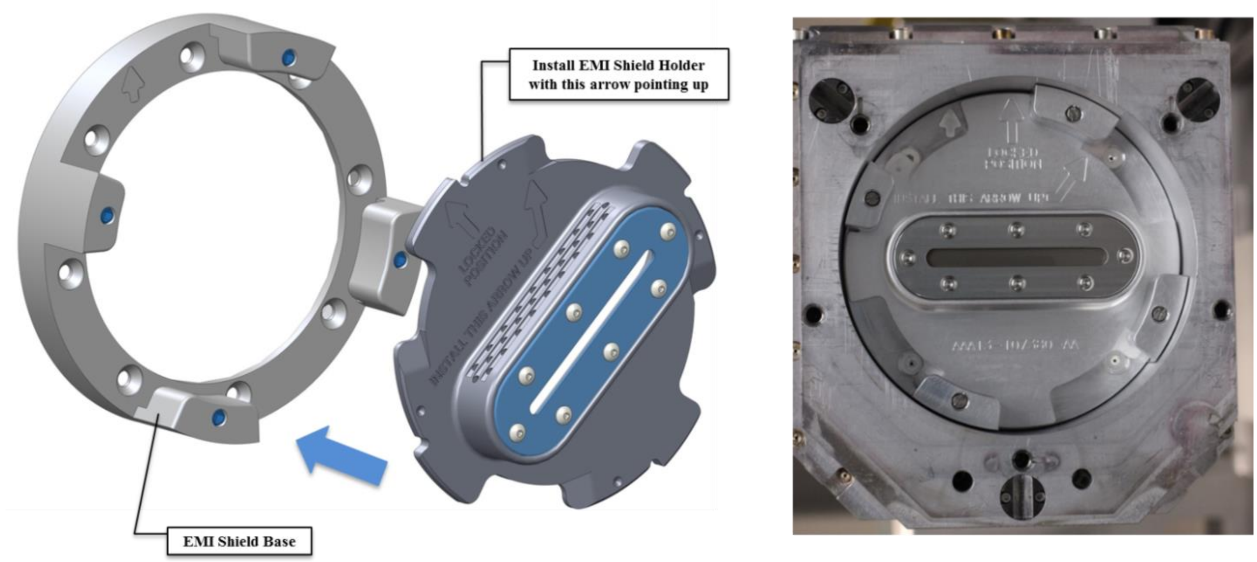


Figure 9: New quick-release EMI shield provides easy access to photocathode pack and a larger aperture for x-ray imaging.

4. PRELIMINARY RESULTS, NEW DESIGN VS. OLD

Test data were taken before and after upgrading a specific x-ray streak camera (DISC-2) to the new design in order to verify the performance improvements of the upgrades. The images shown in Figure 10 are static (unswept) images of the UV spot as it is projected onto the photocathode. The UV source in this case was a Newport model 6047 Hg(Ar) UV pen lamp coupled into the UV fiber at the input of the streak camera. The intensity of the pen lamp is not comparable between the two images, so the amplitudes in the lineouts are arbitrary; the lineouts are vertical and intended primarily to compare spot size and shape. These images show how the hole in the accelerator grid (before upgrade) distorts the apparent size and shape of the UV spot, which should be elliptical. After the hole in the grid was removed (after upgrade), the size and elliptical shape of the spot match the actual optical input; the spot is undistorted.

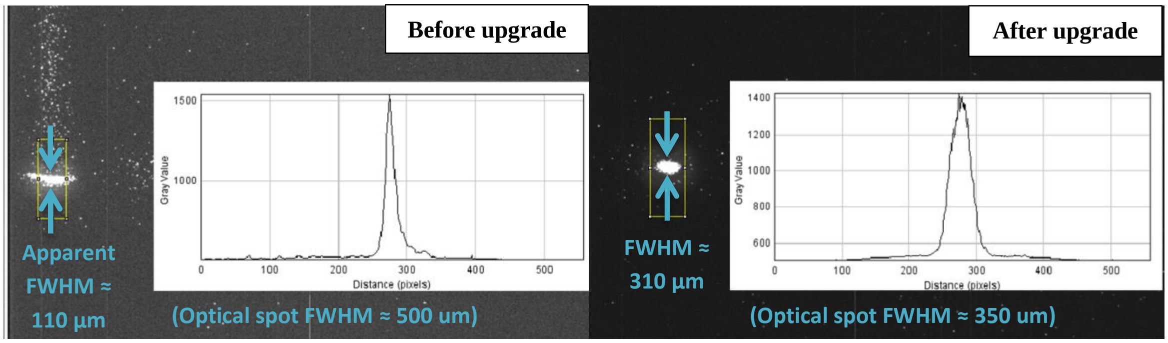


Figure 10: Static (unswept) images of UV spot on photocathode before and after upgrade. Before upgrade, the spot is distorted by the hole in the accelerator grid. After upgrade, the spot is undistorted — elliptical, and a good match to the optical input. Vertical lineouts were taken with a 200 × 560 pixel region of interest (ROI) in both cases to compare spot size and shape, but the amplitudes are not comparable since the UV lamp source intensity was not controlled for the two images.

The images in Figure 11 are from DISC-2 before and after the upgrade, using a slow scan flat field mode (uniform illumination) with an x-ray source (Manson source with Ti anode, predominantly 4.5 keV x-rays). The sweep time is 38 seconds from bottom to top of the images, and the same photocathode was used in both cases. Comparing the two images, one can see that the dead region due to the hole in the accelerator grid (and the corresponding image distortion) have been eliminated after the upgrade. This makes the entire imaging area of the photocathode available for x-ray data in cases where 4ω FIDU is not used.

The most important before-and-after comparison for these upgrades is the performance of the streak camera with a swept data image, running in the same mode as on shots at NIF, including the 4ω FIDU system. This comparison is shown in Figure 12. For both images, the sweep speed is 3 ns (time running from bottom to top in the images, or right to left in the lineouts) and the energy of the 4ω FIDU UV light at the photocathode was measured between 1.3 to 1.5 nJ per individual pulse, so the amplitudes of the 4ω FIDU spots before and after upgrade are directly comparable. The performance improvement is clear. With this low 4ω input energy (1.5 nJ per pulse is ~ 1/3 of the nominal 4ω input energy currently used for streak cameras at NIF), the 4ω FIDU signal before upgrade is barely detectable (~ 10 to 15 counts above background) due to the scattering of the electrons caused by the hole in the accelerator grid. After upgrade, the 4ω FIDU signal level is more than adequate, > 200 counts above background with excellent signal-to-noise, which allows precise determination of spot centroids for accurate timing measurements. This means that the 4ω FIDU system could potentially be operated at NIF at a much lower energy level, which would make the system much more stable, reliable, and much less prone to damage, especially at the pump fiber connector interfaces.

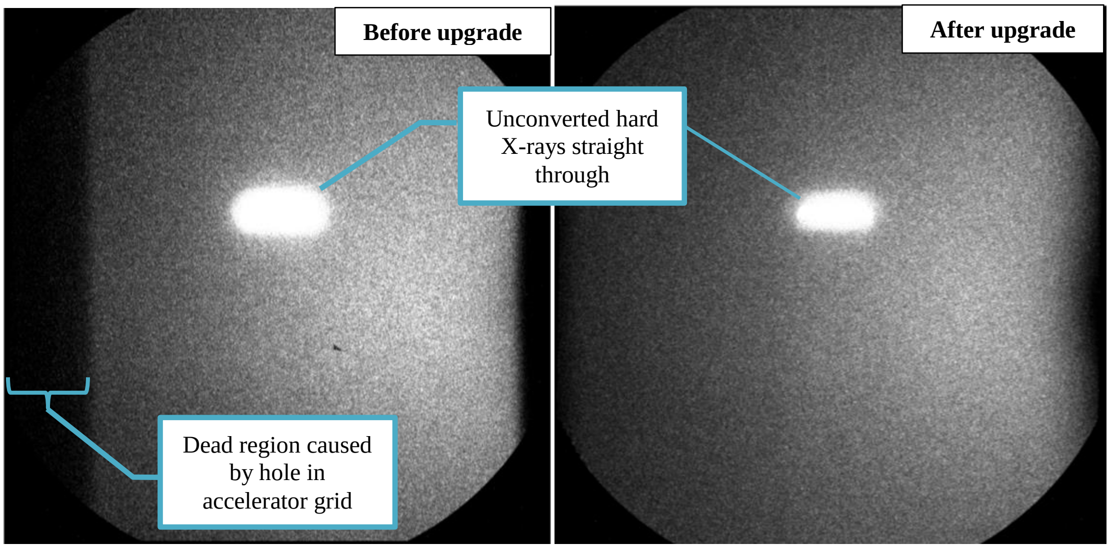


Figure 11: Slow scan flat field images of x-ray streak camera (DISC-2) before and after upgrade. With the new design, the dead region caused by the hole in the accelerator grid has been eliminated, and the full imaging area of the photocathode is available to record data.

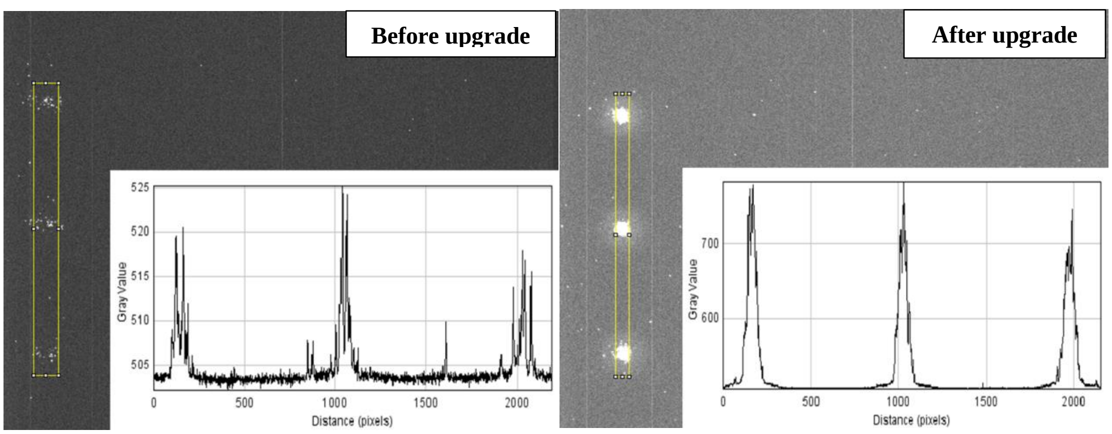


Figure 12: 3ns swept image of the 4ω FIDU pulses before and after upgrade. Both images were taken with approximately the same 4ω input energy (1.3 to 1.5 nJ per pulse at the photocathode). Before upgrade, the 4ω FIDU signal is barely detectable (~ 10 to 15 counts above background), but after upgrade the signal improves markedly to > 200 counts above background.

5. CONCLUSION

Recent upgrades of the photocathode assemblies for x-ray streak cameras at NIF have enabled significant improvements in performance and operational efficiency. Because both the photocathode pack and front EMI shield have been redesigned as self-aligning, tool-less, quick release assemblies, photocathode packs can now be easily replaced between experiments without removing the diagnostic from the DIM, greatly reducing transaction times. The new EMI shield also provides a wider field of view for DISC to support new diagnostics, such as NXS. The 4ω FIDU system provides a means to test and verify the photocathode installation prior to the next experiment, or to perform an operational check of the entire streak camera system any time troubleshooting is required. These operational benefits are in addition to the original purpose of the 4ω FIDU system, which is to serve as a timing reference for sweep linearity correction and cross-timing to the main NIF laser.

Performance improvements include greater precision and repeatability in the photocathode assemblies in the position and rotational alignment of the components, making the streak camera imaging performance more consistent from one photocathode pack to another. This reduces the need to characterize the streak camera (measuring resolution, focus, and dewarp) for each individual photocathode pack (a costly and time-consuming exercise). The new optics for the 4ω FIDU launch allowed removing the problematic hole in the accelerator grid along with the dead zone and distortion it was causing, thereby achieving a significant gain in the 4ω FIDU signal level and making additional area available on the photocathode for data imaging. This will ultimately enable us to operate the 4ω FIDU system at much lower energy levels, making the system more stable, reliable, and robust.

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REFERENCES

[1] Khan, S. F., et al., "Measuring x-ray burn history with the Streaked Polar Instrumentation for Diagnosing Energetic Radiation (SPIDER) at the National Ignition Facility (NIF)," Proc. SPIE 8505, 850505 (2012).

[2] Kimbrough, J. R., et al., "Standard design for National Ignition Facility x-ray streak and framing cameras," Rev. Sci. Instrum. 81, 10E530 (2010).

[3] Opachich, Y. P., et al., "High performance imaging streak camera for the National Ignition Facility," Rev. Sci. Instrum. 83, 125105 (2012).

[4] Kentech Instruments, Ltd. (Isis Building, Howbery Park, Wallingford, Oxfordshire, OX10 8BA.U.K.) Kentech manufactured DISC streak tubes, DISC electronic packages, and GXD electronic packages. www.Kentech.co.uk

[5] Regan, S. P., et al., "Streaked x-ray spectrometer for the National Ignition Facility," these proceedings (Proc. SPIE 9211), Paper 9211-15 (2014).

[6] Homoelle, D., et al., "A compact UV timing fiducial system for use with x-ray streak cameras at NIF," Proc. SPIE 8505, 850504 (2012).

[7] Opachich, Y. P., et al., "X-ray streak camera cathode development and timing accuracy of the 4ω ultraviolet fiducial system at the National Ignition Facility," Rev. Sci. Instrum. 83, 10E123 (2012).

[8] Perfect, B. et al., "A Model to Aid Use and Improvements for NIF's Streak Cameras," poster for LLNL summer student symposium (2012).